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Xu et al.

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(54) **TRAILER SIDESWIPE AVOIDANCE SYSTEM**

(71) Applicant: **Ford Global Technologies, LLC**, Dearborn, MI (US)

(72) Inventors: **Li Xu**, Northville, MI (US); **Martin Miller**, Detroit, MI (US); **Thomas Edward Pilutti**, Ann Arbor, MI (US); **John Michael Celli**, Westland, MI (US)

(73) Assignee: **Ford Global Technologies, LLC**, Dearborn, MI (US)

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B60W 30/09	(2012.01)
B60W 30/095	(2012.01)
B60W 50/14	(2020.01)

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See application file for complete search history.

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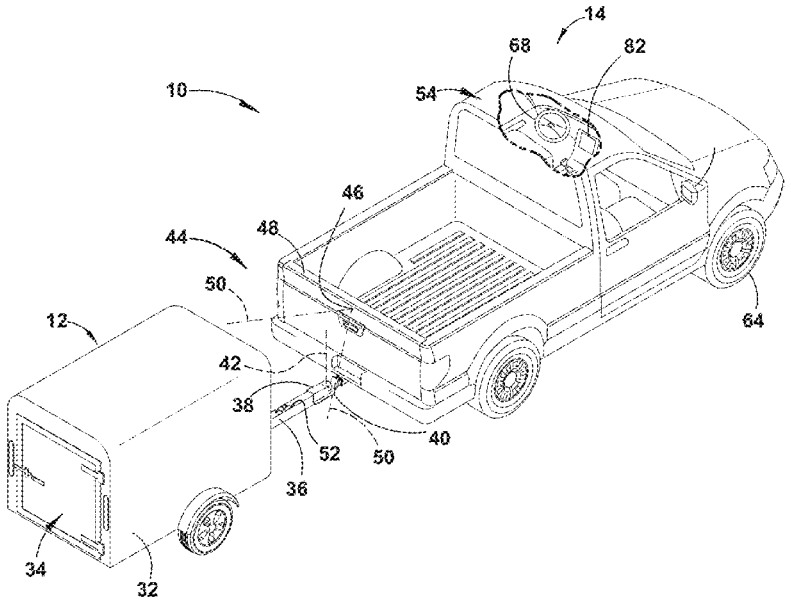
Primary Examiner — Jeff A Burke
Assistant Examiner — Mohamad O El Sayah
(74) *Attorney, Agent, or Firm* — Raymond Coppiellie; Price Heneveld LLP

(57) **ABSTRACT**

A trailer sideswipe avoidance system for a vehicle towing a trailer is provided herein. The trailer sideswipe avoidance system includes a sensor system configured to detect objects in an operating environment of the vehicle. A controller receiving inputs from the sensor system is configured to determine a travel path of the towed trailer as the vehicle turns, determine whether an object detected in the operating environment of the vehicle is in the travel path of the towed trailer, determine a time until sideswiping of the object with the towed trailer, compare the time until sideswiping with a threshold time value, and prompt one or more vehicle systems to execute a sideswipe avoidance measure when the time until sideswiping is less than the threshold time value.

20 Claims, 9 Drawing Sheets



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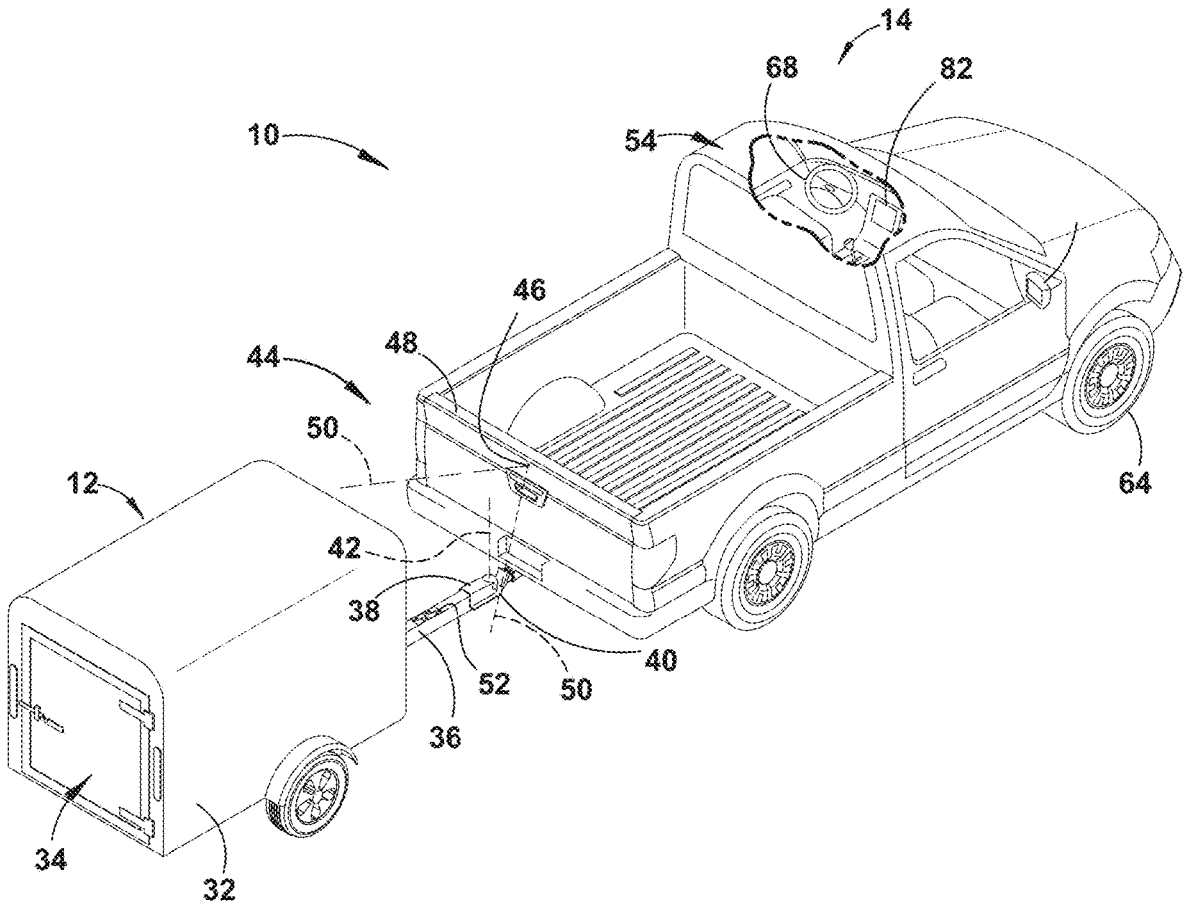

FIG. 1

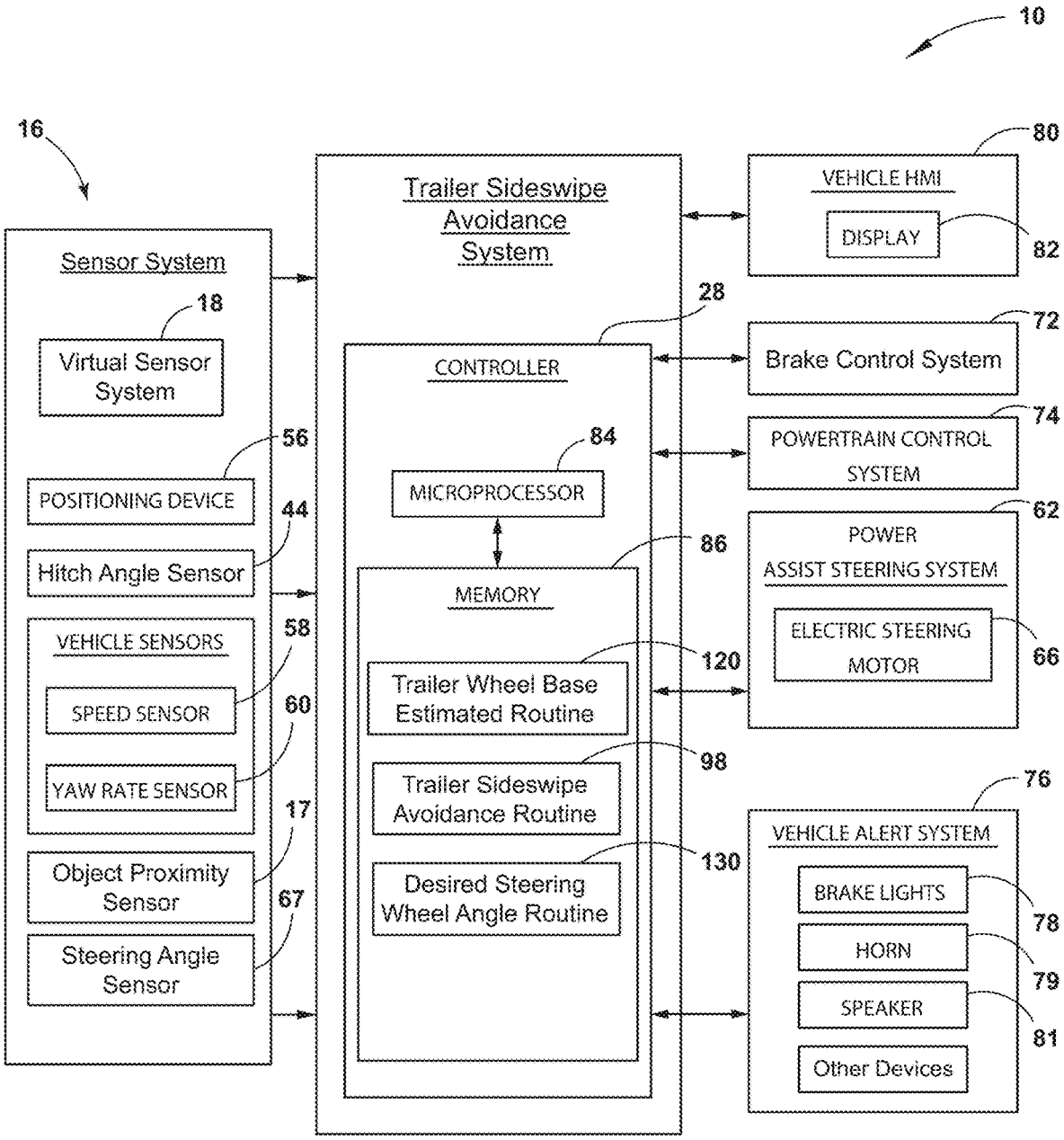
10
16
Sensor System
18
Virtual Sensor System
56
POSITIONING DEVICE
44
Hitch Angle Sensor
VEHICLE SENSORS
58
SPEED SENSOR
60
YAW RATE SENSOR
17
Object Proximity Sensor
67
Steering Angle Sensor
Trailer Sideswipe Avoidance System
28
CONTROLLER
84
MICROPROCESSOR
86
MEMORY
120
Trailer Wheel Base Estimated Routine
98
Trailer Sideswipe Avoidance Routine
130
Desired Steering Wheel Angle Routine
80
VEHICLE HMI
DISPLAY
82
72
Brake Control System
74
POWERTRAIN CONTROL SYSTEM
62
POWER ASSIST STEERING SYSTEM
ELECTRIC STEERING MOTOR
66
76
VEHICLE ALERT SYSTEM
BRAKE LIGHTS
78
HORN
79
SPEAKER
81
Other Devices

FIG. 2

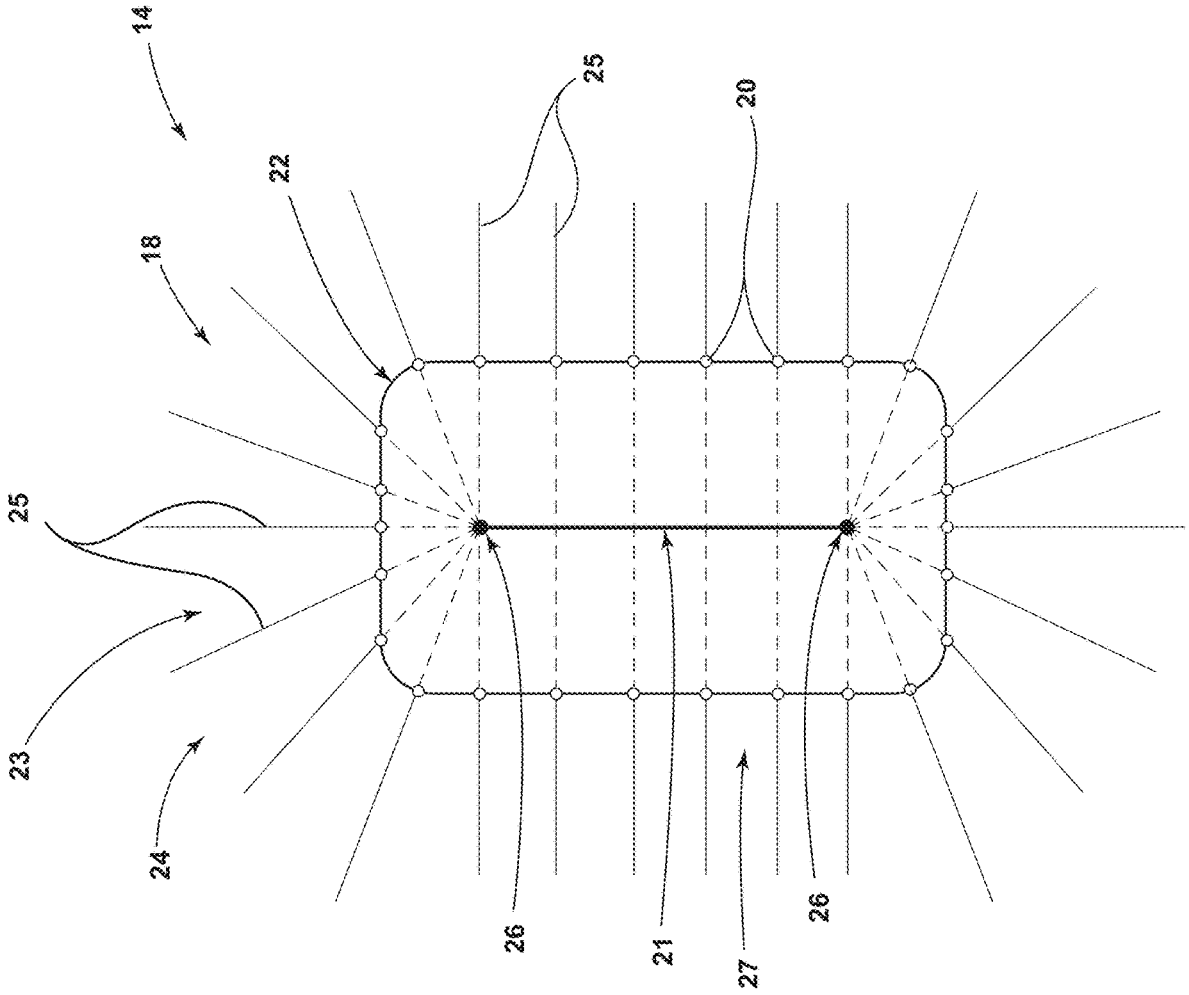

FIG. 3

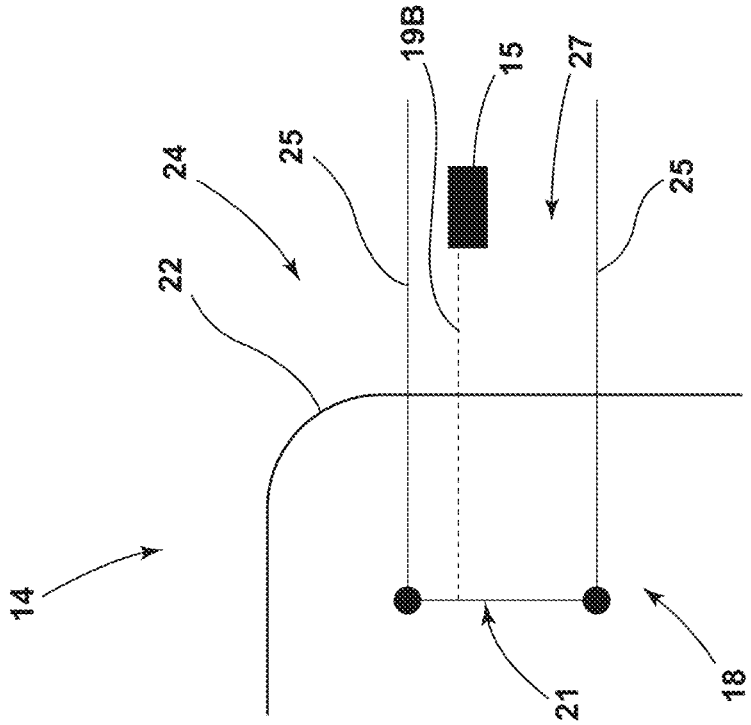

FIG. 4B

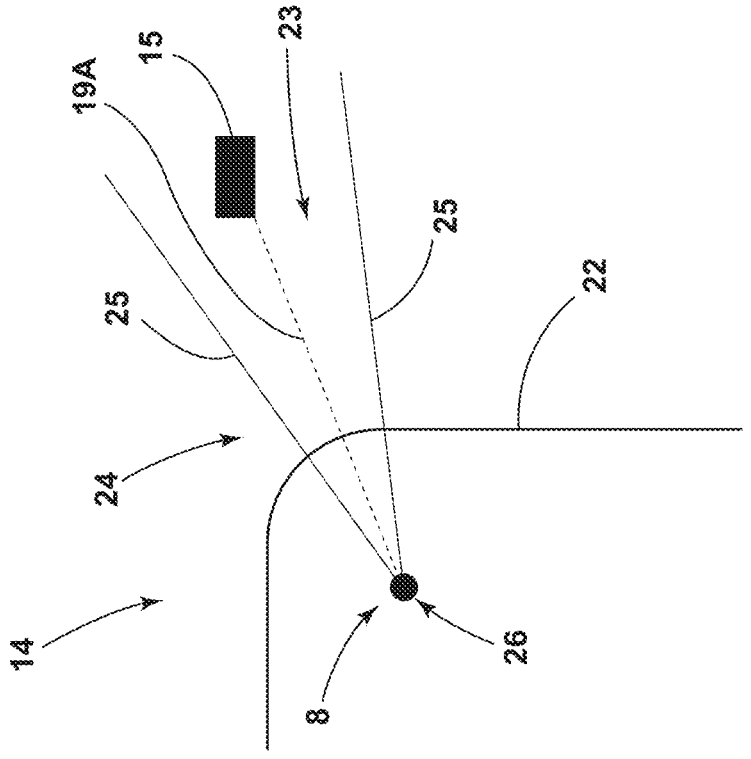

FIG. 4A

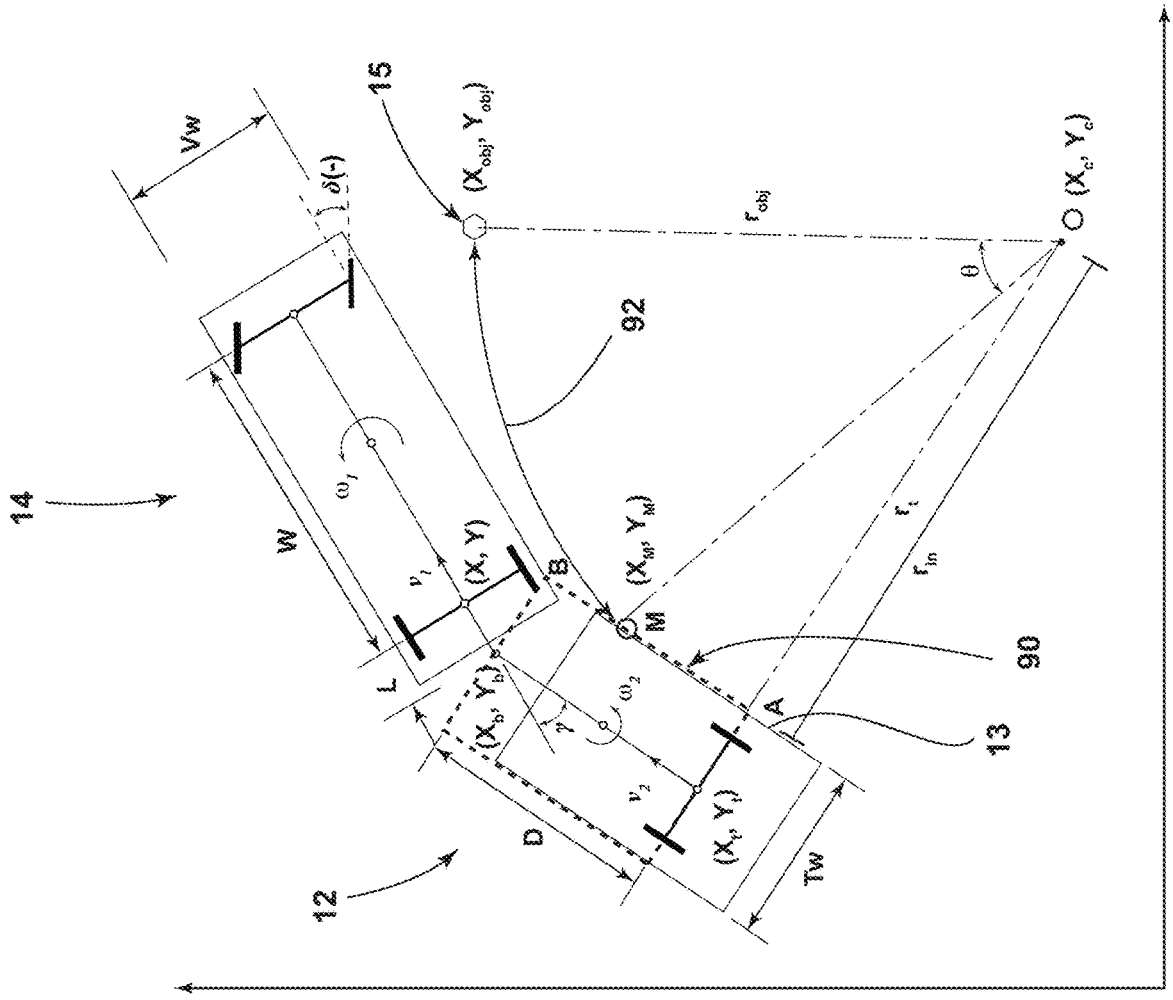
Vw
δ(-)
15
(X_{obj}, Y_{obj})
r_{obj}
(X_c, Y_c)
θ
92
14
W
ω_1
v_1
(X, Y)
B
(X_M, Y_M)
M
r_t
r_{in}
90
L
(X_b, Y_b)
γ
ω_2
A
13
v_2
(X_t, Y_t)
D
Tw
12

FIG. 5

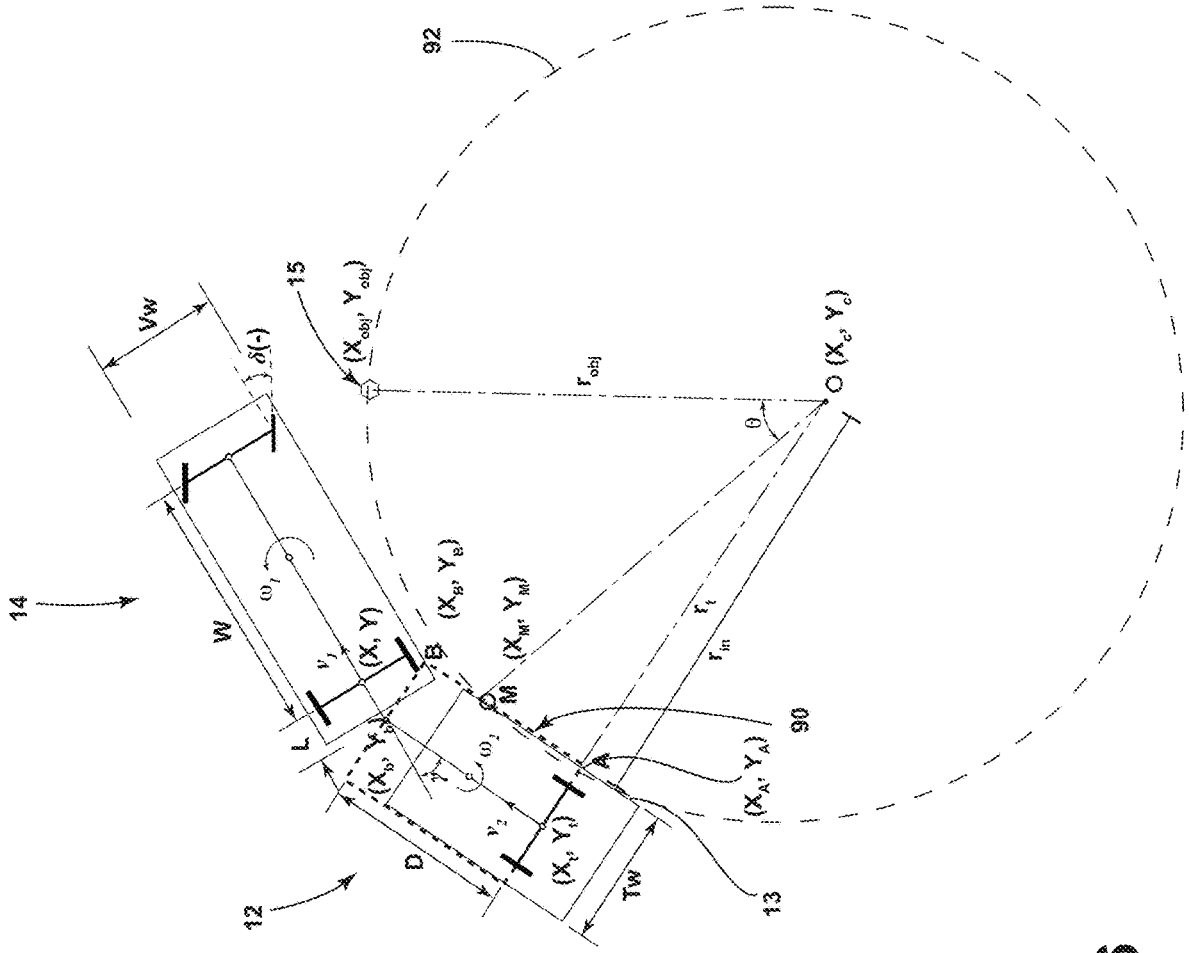
92
15
(X_{obj}, Y_{obj})
r_{obj}
$O(X_c, Y_c)$
θ
Vw
δ(-)
14
W
ω_1
v_1
(X, Y)
B
(X_B, Y_B)
(X_M, Y_M)
M
r_t
r_{in}
90
(X_A, Y_A)
A
L
(X_0, Y_0)
ω_2
v_2
(X_t, Y_t)
D
Tw
12
13

FIG. 6

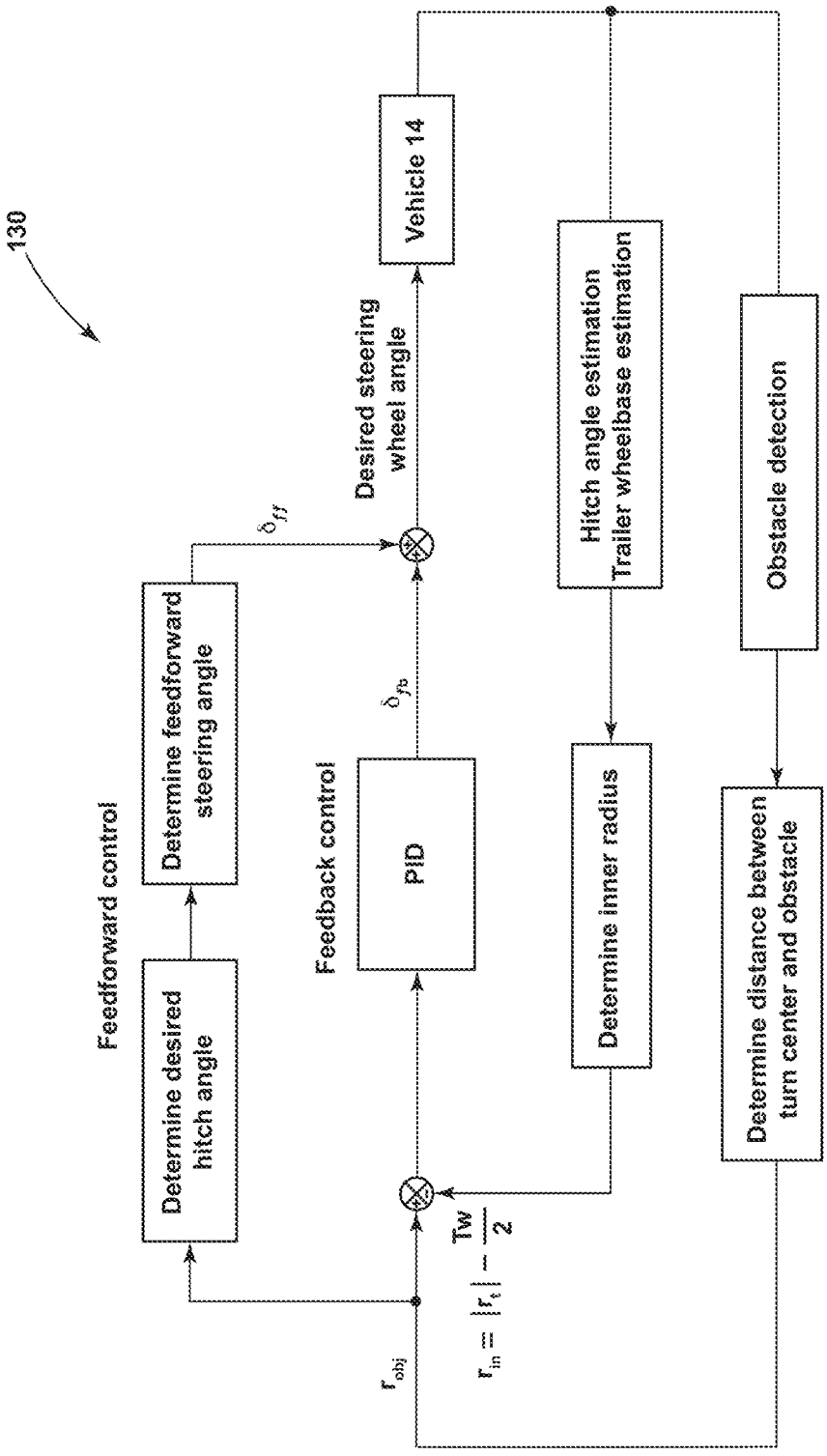
130
Feedforward control
Determine desired hitch angle
Determine feedforward steering angle
Feedback control
PID
Determine inner radius
Determine distance between turn center and obstacle
Obstacle detection
Hitch angle estimation
Trailer wheelbase estimation
Desired steering wheel angle
Vehicle 14
δ_{ff}
δ_{fb}
r_{obj}
$r_{in} = |r_t| - \frac{Tw}{2}$

FIG. 7

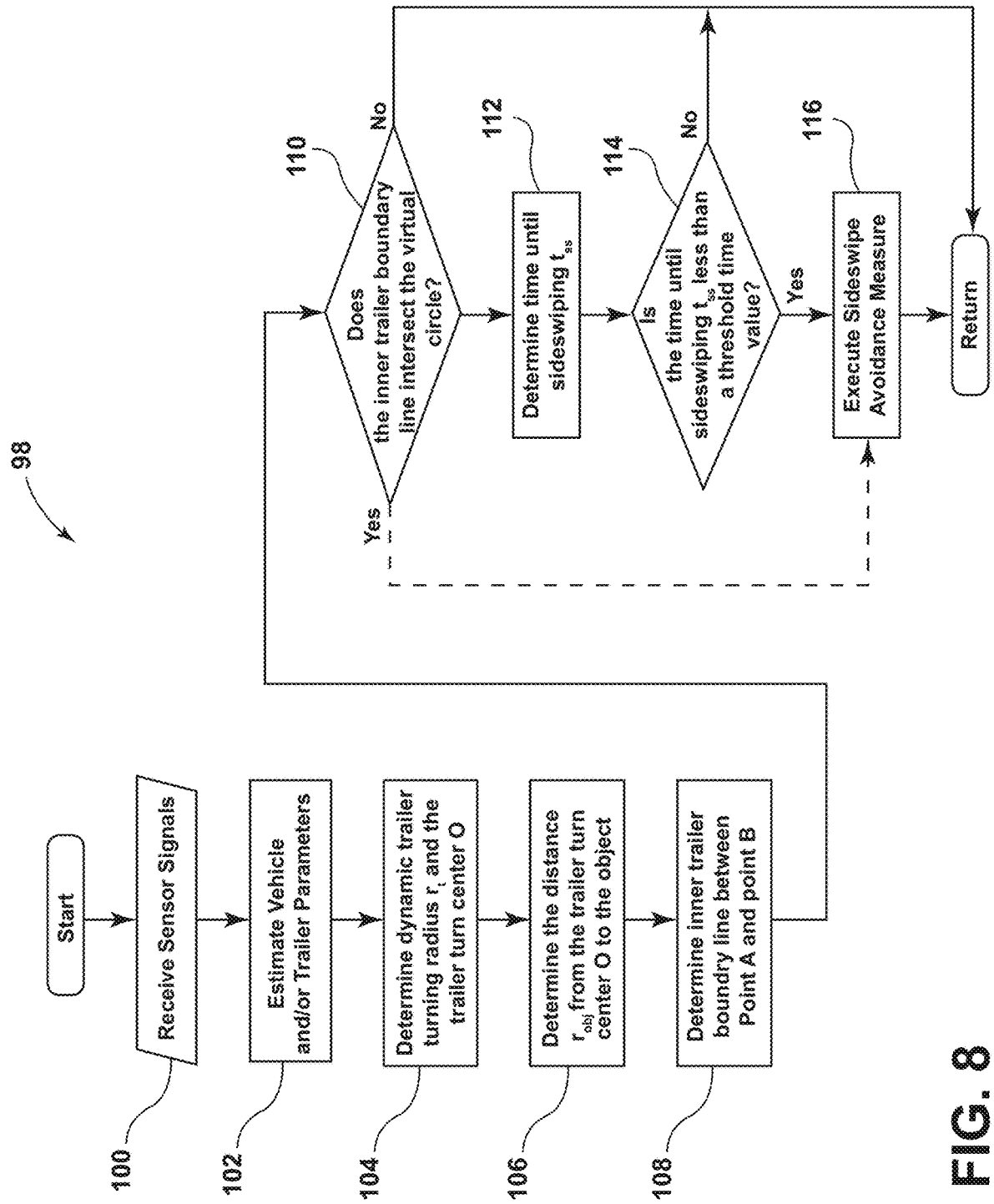
98
Start
Receive Sensor Signals
Estimate Vehicle and/or Trailer Parameters
Determine dynamic trailer turning radius r_t and the trailer turn center O
Determine the distance r_{obj} from the trailer turn center O to the object
Determine inner trailer boundry line between Point A and point B
100
102
104
106
108
110
Does the inner trailer boundary line intersect the virtual circle?
No
Yes
112
Determine time until sideswiping t_{ss}
114
Is the time until sideswiping t_{ss} less than a threshold time value?
No
Yes
116
Execute Sideswipe Avoidance Measure
Return

FIG. 8

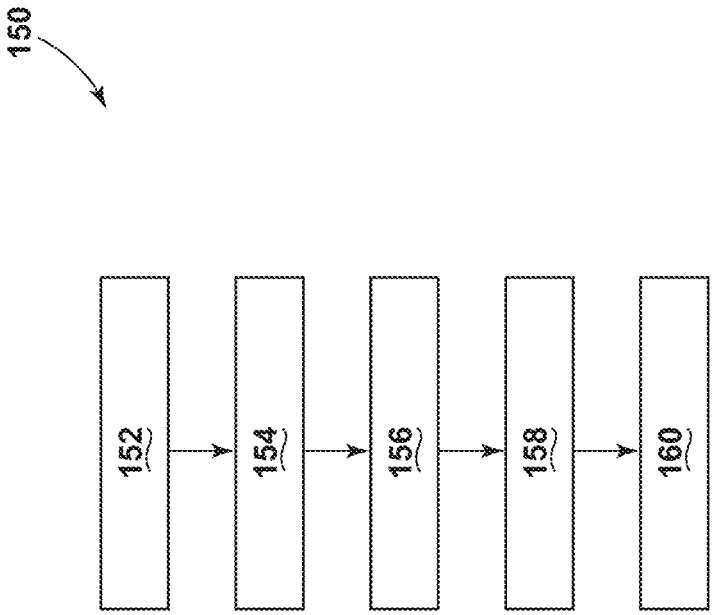

FIG. 9

TRAILER SIDESWIPE AVOIDANCE SYSTEM

FIELD OF THE INVENTION

The present invention generally relates to trailer towing, and more particularly relates to sideswipe detection and avoidance system for vehicles towing trailers.

BACKGROUND OF THE INVENTION

A trailer being towed by a vehicle does not follow the exact path of the vehicle as the vehicle turns. As such, towing a trailer around curves may be challenging for drivers.

SUMMARY OF THE INVENTION

According to one aspect of the present invention, a trailer sideswipe avoidance system for a vehicle towing a trailer includes a sensor system configured to detect objects in an operating environment of the vehicle. A controller is configured to process information received from the sensor system to determine whether an object detected in the operating environment of the vehicle is in a travel path of the towed trailer as the vehicle turns, wherein the controller is further configured to prompt one or more vehicle systems to execute a sideswipe avoidance measure based on a determination that the object is in the travel path of the towed trailer.

Embodiments of the first aspect of the invention can include any one or a combination of the following features:

- the sideswipe avoidance measure comprises reducing manual steering torque assist supplied by a power assist steering system;
- the sideswipe avoidance measure comprises executing a warning signal via a vehicle alert system;
- the sideswipe avoidance measure comprises reducing the speed of the vehicle;
- the sideswipe avoidance measure comprises reducing a steering angle of the vehicle such that the dynamic turning radius of the vehicle increases;
- the controller is further configured to determine a time until sideswiping of the object with the towed trailer;
- the controller is further configured to prompt one or more vehicle systems to execute the sideswipe avoidance measure when the time until sideswiping is less than a predetermined threshold time value; and
- the controller is further configured to prompt one or more vehicle systems to execute a first sideswipe avoidance measure when the time until sideswiping is less than a first predetermined threshold time value and prompt one or more vehicle systems to execute a second sideswipe avoidance measure when the time until sideswiping is less than a second predetermined threshold time value, wherein the first predetermined threshold time value is greater than the second predetermined threshold time value.

According to another aspect of the present invention, a trailer sideswipe avoidance system for a vehicle towing a trailer includes a sensor system configured to detect objects in an operating environment of the vehicle. A controller receives inputs from the sensor system and is configured to determine a travel path of the towed trailer as the vehicle turns, determine whether an object detected in the operating environment of the vehicle is in the travel path of the towed trailer, determine a time until sideswiping of the object with the towed trailer, compare the time until sideswiping with a threshold time value, and prompt one or more vehicle systems to execute a sideswipe avoidance measure when the time until sideswiping is less than the threshold time value.

Embodiments of the second aspect of the invention can include any one or a combination of the following features:

- the sideswipe avoidance measure comprises reducing manual steering torque assist supplied by a power assist steering system;
- the sideswipe avoidance measure comprises executing a warning signal via a vehicle alert system;
- the sideswipe avoidance measure comprises reducing the speed of the vehicle; and
- the sideswipe avoidance measure comprises reducing a steering angle of the vehicle such that the dynamic turning radius of the vehicle increases.

According to yet another aspect of the present disclosure, a method for operating a trailer sideswipe avoidance system includes the steps of: turning a vehicle towing a trailer, determining a dynamic trailer turning radius and a trailer turn center, detecting an object with a sensor system of the vehicle, determining a distance from the trailer turn center to the object, determining whether an inner trailer boundary line intersects a virtual circle having a center point at the trailer turn center and a radius equal to the distance from the trailer turn center to the object, and executing a sideswipe avoidance measure based on the inner trailer boundary line intersecting the virtual circle.

Embodiments of the third aspect of the invention can include any one or a combination of the following steps and/or features:

- the inner trailer boundary line extends between a first point and a second point, the first point is located proximate to an intersection between an inner side of the trailer and a line running along the axis of a trailer axle, and the second point is displaced from the first point a distance generally equal to the length of the trailer wheel base in the trailer forward direction substantially parallel to a longitudinal centerline of the trailer, wherein the inner side of the trailer corresponds with a turning direction of the vehicle;
- determining a time until sideswiping based on a speed of the trailer, the dynamic trailer turning radius, and the angle between a line extending from the trailer turn center to the object and a line extending from the trailer turn center to an intersection point of the inner trailer boundary line and the virtual circle;
- comparing the time until sideswiping with a predetermined threshold time value and executing the sideswipe avoidance measure when the time until sideswiping is less than the predetermined threshold time value;
- executing a warning signal via a vehicle alert system;
- reducing a steering angle of the vehicle such that the inner trailer boundary line no longer intersects the virtual circle; and
- reducing manual steering torque assist supplied by a power assist steering system.

These and other aspects, objects, and features of the present invention will be understood and appreciated by those skilled in the art upon studying the following specification, claims, and appended drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. **1** is a top perspective view of a vehicle attached to a trailer with a hitch angle sensor of a sensor system of the

vehicle for operating a trailer sideswipe avoidance system, according to one embodiment;

FIG. **2** is a block diagram illustrating the trailer sideswipe avoidance system, having the sensor system, a controller, and various other vehicle systems, according to one embodiment;

FIG. **3** is a top-down representation of spatial segmentation of an operating environment of the vehicle output by a virtual sensor system, according to one embodiment;

FIG. **4**A is top-down representation of a portion of the spatial segmentation output by the virtual sensor system, illustrating an object between upper and lower boundary vectors of a point-based segment, according to one embodiment;

FIG. **4**B is top-down representation of a portion of the spatial segmentation output by the virtual sensor system, illustrating the object between upper and lower boundary vectors of a line-based segment, according to one embodiment;

FIG. **5** is a schematic diagram that illustrates the geometry of the vehicle, the trailer, and the object overlaid with a two dimensional x-y coordinate system, identifying variables and parameters used in operation of the trailer sideswipe avoidance system, according to one embodiment;

FIG. **6** is a schematic diagram of the geometry of the vehicle, the trailer, and the object, illustrating a virtual circle intersecting an inner trailer boundary line, according to one embodiment;

FIG. **7** is a schematic block diagram illustrating the flow of logic in a controller for achieving a desired steering wheel angle during operating of the trailer sideswipe avoidance system, according to one embodiment;

FIG. **8** is a flow diagram illustrating a trailer sideswipe avoidance routine, according to one embodiment; and

FIG. **9** is a block diagram illustrating a method of operating the trailer sideswipe avoidance system, according to one embodiment.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Additional features and advantages of the invention will be set forth in the detailed description which follows and will be apparent to those skilled in the art from the description, or recognized by practicing the invention as described in the following description, together with the claims and appended drawings.

As used herein, the term "and/or," when used in a list of two or more items, means that any one of the listed items can be employed by itself, or any combination of two or more of the listed items can be employed. For example, if a composition is described as containing components A, B, and/or C, the composition can contain A alone; B alone; C alone; A and B in combination; A and C in combination; B and C in combination; or A, B, and C in combination.

In this document, relational terms, such as first and second, top and bottom, and the like, are used solely to distinguish one entity or action from another entity or action, without necessarily requiring or implying any actual such relationship or order between such entities or actions.

For purposes of this disclosure, the term "coupled" (in all of its forms: couple, coupling, coupled, etc.) generally means the joining of two components (electrical or mechanical) directly or indirectly to one another. Such joining may be stationary in nature or movable in nature. Such joining may be achieved with the two components (electrical or mechanical) and/or any additional intermediate members. Such joining may include members being integrally formed as a single unitary body with one another (i.e., integrally coupled) or may refer to joining of two components. Such joining may be permanent in nature, or may be removable or releasable in nature, unless otherwise stated.

The terms "substantial," "substantially," and variations thereof as used herein are intended to note that a described feature is equal or approximately equal to a value or description. For example, a "substantially planar" surface is intended to denote a surface that is planar or approximately planar. Moreover, "substantially" is intended to denote that two values are equal or approximately equal. In some embodiments, "substantially" may denote values within about 10% of each other, such as within about 5% of each other, or within about 2% of each other.

As used herein the terms "the," "a," or "an," mean "at least one," and should not be limited to "only one" unless explicitly indicated to the contrary. Thus, for example, reference to "a component" includes embodiments having two or more such components unless the context clearly indicates otherwise.

In reference to FIGS. **1-9**, a trailer sideswipe avoidance system **10** for a vehicle **14** towing a trailer **12** is disclosed. The trailer sideswipe avoidance system **10** may include a sensor system **16** configured to detect objects **15** in an operating environment **24** of the vehicle **14**. The trailer sideswipe avoidance system **10** may include a controller **28** receiving inputs from the sensor system **16** and configured to determine a travel path of the towed trailer **12** as the vehicle **14** turns, determine whether the object **15** detected in the operating environment of the vehicle **14** is in the travel path of the towed trailer **12**, determine a time until sideswiping t_{ss} of the object **15** with the towed trailer **12**, compare the time until sideswiping t_{ss} with a threshold time value, and prompt one or more vehicle systems to execute a sideswipe avoidance measure when the time until sideswiping t_{ss} is less than the threshold time value.

With reference to the embodiment shown in FIG. **1**, the vehicle **14** is a pickup truck embodiment that is equipped with one embodiment of the trailer sideswipe avoidance system **10** for monitoring and/or controlling the path of the trailer **12** that is attached to the vehicle **14**. Specifically, the vehicle **14** is pivotally attached to one embodiment of the trailer **12** that has a box frame **32** with an enclosed cargo area **34** and a tongue **36** longitudinally extending forward from the enclosed cargo area **34**. The illustrated trailer **12** also has a trailer hitch connector in the form of a coupler assembly **38** that is connected to a vehicle hitch connector in the form of a hitch ball **40**. The coupler assembly **38** latches onto the hitch ball **40** to provide a pivoting ball joint connection **42** that allows for articulation of the hitch angle γ. It should be appreciated that additional embodiments of the trailer **12** may include more than one axle; may have various shapes and sizes configured for different loads and items, such as a boat trailer or a flatbed trailer; and may alternatively couple with the vehicle **14** to provide a pivoting connection, such as by connecting with a fifth wheel connector.

Referring now to FIG. **2**, the vehicle **14** may include a sensor system **16** having a plurality of sensors configured to detect objects **15** in the operating environment **24** of the vehicle **14** that may be in a potential travel path of the trailer **12**. The plurality of sensors may include one or a combination of visual sensors (e.g., cameras, surround view cameras, etc.), radar sensors, Lidar sensors, ultrasonic sensors, lasers, thermal sensors, and/or various other sensors. For example, in some embodiments, the vehicle **14** may include ultrasonic sensors, surround view cameras, radar sensors disposed on

the corners and front of the vehicle **14**, and a camera on the front of the vehicle **14**. It is contemplated that the plurality of sensors in the sensor system **16** may be located in various positions on the vehicle **14**. It is further contemplated that, in some embodiments, one or more of the plurality of sensors may be coupled to the trailer **12** in addition to the one or more sensors coupled to the vehicle **14**. The sensor system **16** may be configured to provide sensed inputs to the controller **28**. In various embodiments, the data collected from the plurality of sensors in the sensor system **16** may be utilized by the controller **28** to map the features detected within the operating environment **24** of the vehicle **14**. The features detected within the operating environment **24** of the vehicle **14** may include, but are not limited to, the vehicle **14**, the trailer **12**, and objects **15**, such as moving and stationary objects **15** within a prescribed distance of the vehicle **14** and/or the trailer **12**.

Referring now to FIG. **3**, in some embodiments, the data collected from the variety of sensor types (e.g., visual, radar, ultrasonic) may be fused (sensor fusion) to simulate virtual sensors **20** positioned on the vehicle **14**. The virtual sensor system **18** that results from the fusion of various sensor inputs may be configured to output a spatial segmentation of the operating environment **24** of the vehicle **14**. In some embodiments, the spatial segmentation of the operating environment **24** of the vehicle **14** may be output as a two dimensional representation of the operating environment **24** of the vehicle **14** from a top-down perspective, as shown in FIG. **3**. In operation, objects **15** detected by the virtual sensor system **18** within the operating environment **24** of the vehicle **14** may be represented by a distance from the detected object **15** to a delineated vehicle boundary **22**. In some embodiments, the detected object **15** may further be represented by the object's **15** determined position within a 2D world coordinate frame of the operating environment **24** of the vehicle **14**. In various embodiments, the delineated vehicle boundary **22** may generally trace the contour of the exterior of the vehicle **14** from a top-down perspective, as shown in FIG. **3**. However, it is contemplated that the delineated vehicle boundary **22** may deviate from the literal boundary of the vehicle **14** by design.

In various embodiments, the spatial segmentation of the operating environment **24** of the vehicle **14** may include a variety of segment types. For example, as shown in FIGS. **3** and **4**A, the spatial segmentation may include point-based segments **23** that are defined by lower and upper boundary vectors **25** originating from a common reference point **26**. In various embodiments, the common reference point **26** may be disposed within the delineated vehicle boundary **22**, and the upper and lower boundary vectors **25** may extend therefrom across the delineated vehicle boundary **22** into the operating environment **24** surrounding the vehicle **14**. However, it is contemplated that the common reference point **26** may be positioned proximate to the delineated vehicle boundary **22**. The determined distance of the object **15** detected within the point-based segment **23** from the delineated vehicle boundary **22** may be defined by the Euclidean distance between the nearest detected point of the object **15** and the delineated vehicle boundary **22** along a line **19**A between the common reference point **26** and the nearest detected point of the object **15**.

Referring now to FIGS. **3** and **4**B, the spatial segmentation may further include line-based segments **27** that are defined by lower and upper boundary vectors **25** extending from points on a common reference line **21**. The determined distance of the object **15** detected within the line-based segment **27** from the delineated vehicle boundary **22** may be defined by the Euclidean distance between the nearest detected point of the object **15** and the delineated vehicle boundary **22** along a line **19**B between the nearest point on the common reference line **21** and the nearest detected point of the object **15**. It is contemplated that, in various embodiments, the vehicle **14** may include a plurality of common reference points **26** and/or common reference lines **21** from which boundary vectors **25** extend to define respective segments, as may be suitable to tailor the segments of the virtual sensor system **18** to the contours of a given delineated vehicle boundary **22**.

In various embodiments, the virtual sensor system **18** may be utilized by the trailer sideswipe avoidance system **10** to identify and characterize objects **15** within the operating environment **24** of the vehicle **14**. In particular, the virtual sensor system **18** may provide information to the trailer sideswipe avoidance system **10** regarding trailer width Tw, and/or hitch angle γ of the trailer **12** being towed by the vehicle **14**, as well as the delineated vehicle boundary **22** of the vehicle **14**, and moving or stationary objects **15** within the operating environment **24** of the vehicle **14**. With respect to trailer width Tw, in some embodiments, the furthest lateral points of the trailer **12** detected by the virtual sensor system **18** may provide a trailer width estimate. In some embodiments, in which the position of the corners of the trailer **12** are determined, trailer width Tw may be defined by the Euclidean distance between the determined corners. Further, in this embodiment, the hitch angle γ may be defined by the angle between the vehicle **14** and a line normal to a vector extending between the determined corner positions of the trailer **12**. It is contemplated that, the virtual sensor system **18** may determine vehicle **14**, trailer **12**, and object **15** parameters in addition to those discussed herein, and it is further contemplated that, in some embodiments, the sensor system **16** may determine trailer width Tw, hitch angle γ, the position of the vehicle **14**, and the position and/or path of objects **15** in the operating environment **24** of the vehicle **14** by means other than the virtual sensor system **18** described herein.

For example, with respect to determining hitch angle γ, in some embodiments, the sensor system **16** may include a vision based hitch angle sensor **44** for sensing the hitch angle γ between the vehicle **14** and the trailer **12**, as shown in FIG. **1**. In such an embodiment, the hitch angle sensor **44** may employ a camera **46** (e.g. video imaging camera) that may be located proximate an upper region of the vehicle tailgate **48** at the rear of the vehicle **14**, such that the camera **46** may be elevated relative to the tongue **36** of the trailer **12**. The camera **46** may include an imaging field of view **50** located and oriented to capture one or more images of the trailer **12**, including a region containing one or more desired target placement zones for at least one target **52** to be secured. It is contemplated that the camera **46** may capture images of the trailer **12** without a target **52** to determine the hitch angle γ. However, the trailer sideswipe avoidance system **10** may utilize one or more targets **52** placed on the trailer **12** to allow the trailer sideswipe avoidance system **10** to utilize information acquired via image acquisition and processing of the target **52**. For instance, the camera **46** may include a video imaging camera that repeatedly captures successive images of the trailer **12** that may be processed to identify the target **52** and its location on the trailer **12** for determining movement of the target **52** and the trailer **12** relative to the vehicle **14** and the corresponding hitch angle γ. It should also be appreciated that the camera **46** may include one or more video imaging cameras and may be located at other locations on the vehicle **14** to acquire images of the trailer **12** and the

desired target placement zone, such as on a passenger cab **54** of the vehicle **14** to capture images of a gooseneck trailer. Furthermore, it is contemplated that additional embodiments of the hitch angle sensor **44** and the sensor system **16** for providing the hitch angle γ may include one or a combination of a potentiometer, a magnetic-based sensor, an optical sensor, a proximity sensor, a rotational sensor, a capacitive sensor, an inductive sensor, or a mechanical based sensor, such as a mechanical sensor assembly mounted to the pivoting ball joint connection **42**, a yaw rate sensor **60** on the trailer **12** and the vehicle **14**, energy transducers of a reverse aid system, a blind spot system, and/or a cross traffic alert system, and other conceivable sensors or indicators of the hitch angle γ to supplement or be used in place of the vision based hitch angle sensor **44**.

Further, with respect to determining the position of the vehicle **14**, in some embodiments, the trailer sideswipe avoidance system **10** may receive vehicle status-related information from additional sensors and devices. This information may include positioning information from a positioning device **56**, which may include a global positioning system (GPS) on the vehicle **14** or a handled device, to determine a coordinate location of the vehicle **14** and the trailer **12** based on the location of the positioning device **56** with respect to the trailer **12** and/or the vehicle **14** and based on the sensed hitch angle γ. The positioning device **56** may additionally or alternatively include a dead reckoning system for determining the coordinate location of the vehicle **14** and the trailer **12** within a localized coordinate system based at least on vehicle speed v_1, steering angle δ, and hitch angle γ. Other vehicle information received by the trailer sideswipe avoidance system **10** may include a speed v_1 of the vehicle **14** from a speed sensor **58** and a yaw rate ω_1 of the vehicle **14** from the yaw sensor **60**.

Further still, with respect to detecting potential obstacles, in some embodiments, the sensor system **16** of the trailer sideswipe avoidance system **10** may include an object proximity sensor **17** that provides the proximity of an object **15** to the controller **28** of the trailer sideswipe avoidance system **10**. More specifically, the object proximity sensor **17** may provide the trailer sideswipe avoidance system **10** with proximity information of the object **15**, which may include information estimating a location of the object **15** or objects **15** relative to the vehicle **14** and/or trailer **12**. The object proximity sensor **17** may include an individual sensor, multiple sensors, and various combinations of sensors and sensor systems to capture, generate, and output information characterizing the proximity of the object **15** adjacent to the vehicle **14** and/or trailer **12**, as described in more detail herein. Accordingly, the object proximity sensor **17** may include portions of or be incorporated with the hitch angle sensor **44**, the positioning device **56**, or other additional sensors and devices. The trailer sideswipe avoidance system **10** may use the proximity information of the object **15** or objects **15** as an input to the controller **28** to warn of or avoid a collision with the object **15** or objects **15**, as disclosed in greater detail below.

Referring now to FIG. **2**, in some embodiments, the trailer sideswipe avoidance system **10** is in communication with a power assist steering system **62** of the vehicle **14** to operate the steered wheels **64** (FIG. **1**) of the vehicle **14** for moving the vehicle **14** in such a manner that the trailer **12** reacts in accordance with the desired path of the trailer **12**. In some embodiments, the power assist steering system **62** may be an electric power-assisted steering (EPAS) system that includes an electric steering motor **66** for turning the steered wheels **64** to a steering angle δ based on a steering command, whereby the steering angle δ may be sensed by a steering angle sensor **67** of the power assist steering system **62**. The steering command may be provided by the trailer sideswipe avoidance system **10** for autonomously steering or inhibiting manual steering during a potential trailer sideswipe event and may alternatively be provided manually via a rotational position (e.g., steering wheel angle) of a steering wheel **68** (FIG. **1**).

Referring further to FIG. **2**, the power assist steering system **62** provides the controller **28** of the trailer sideswipe avoidance system **10** with information relating to a rotational position of steered wheels **64** of the vehicle **14**, including the steering angle δ. In some embodiments, the controller **28** may process the current steering angle δ, in addition to other vehicle **14** and trailer **12** conditions, to tow the trailer **12** along a desired path. It is conceivable that the trailer sideswipe avoidance system **10**, in additional embodiments, may be an integrated component of the power assist steering system **62**. For example, the power assist steering system **62** may include a trailer sideswipe warning algorithm for generating vehicle steering information and commands as a function of all or a portion of information received from the sensor system **16**, power assist steering system **62**, a vehicle brake control system **72**, a powertrain control system **74**, and/or other vehicle sensors and devices.

In further reference to FIG. **2**, the vehicle brake control system **72** may also communicate with the controller **28** to provide the trailer sideswipe avoidance system **10** with braking information, such as vehicle wheel speed, and to receive braking commands from the controller **28**. For instance, vehicle speed information can be determined from individual wheel speeds as monitored by the brake control system **72**. Vehicle speed v_1 may also be determined from the powertrain control system **74**, the speed sensor **58**, and the positioning device **56**, among other conceivable means. In some embodiments, individual wheel speeds can also be used to determine a vehicle yaw rate ω_1, which can be provided to the trailer sideswipe avoidance system **10** in the alternative or in addition to the vehicle yaw rate sensor **60**. In certain embodiments, the trailer sideswipe avoidance system **10** can provide vehicle braking information to the brake control system **72** for allowing the trailer sideswipe avoidance system **10** to control braking of the vehicle **14** during towing of the trailer **12**. For example, the trailer sideswipe avoidance system **10** in some embodiments may regulate speed of the vehicle **14** while maneuvering the trailer **12** around turns or when objects **15** are detected, which can reduce the potential for sideswipe events, as will be further discussed below.

The powertrain control system **74**, as shown in the embodiment illustrated in FIG. **2**, may also interact with the trailer sideswipe avoidance system **10** for regulating speed and acceleration of the vehicle **14** during towing of the trailer **12**. As mentioned above, regulation of the speed of the vehicle **14** may be necessary to limit the potential for sideswipe events. Similar to high-speed considerations as they relate to risk of a sideswipe event, high acceleration and sharp turns by the driver may also lead to potential sideswipe events.

With continued reference to FIG. **2**, the trailer sideswipe avoidance system **10** in the illustrated embodiment may communicate with one or more devices, including a vehicle alert system **76**, which may prompt visual, auditory, and/or tactile warnings signals. For instance, vehicle brake lights **78** and vehicle emergency flashers may provide a visual alert and a vehicle horn **79** and/or speaker **81** may provide an audible alert. Additionally, the trailer sideswipe avoidance

system **10** and/or vehicle alert system **76** may communicate with a human machine interface (HMI) **80** for the vehicle **14**. The HMI **80** may include a vehicle display **82**, such as a center-stack mounted navigation or entertainment display (FIG. **1**). Further, the trailer sideswipe avoidance system **10** may communicate via wireless communication with another embodiment of the HMI **80**, such as with one or more handheld or portable devices, including one or more smartphones. The portable device may also include the display **82** for displaying one or more images and other information to a user. In addition, the portable device may provide feedback information, such as warning signals that are visual, audible, tactile, and/or a combination thereof.

As further illustrated in FIG. **2**, the controller **28** is configured with a microprocessor **84** to process logic and routines stored in memory **86** that receive information from the sensor system **16**, the power assist steering system **62**, the vehicle brake control system **72**, the trailer braking system, the vehicle alert system **76**, the powertrain control system **74**, and other vehicle sensors and devices. The controller **28** may generate warnings, as well as vehicle steering information and commands as a function of all or a portion of the information received. Thereafter, the vehicle steering information and commands may be provided to the power assist steering system **62** for affecting steering of the vehicle **14** to avoid a path of travel leading to a sideswipe event, inhibit manual steering into a path of travel leading to a sideswipe event, and/or modify a path of travel to prevent an imminent sideswipe event of the trailer **12**. Additionally, the controller **28** may be configured to prompt one or more vehicle systems (e.g., vehicle alert system **76**, vehicle brake control system **72**, etc.) to execute one or more sideswipe avoidance measures, as will be discussed in more detail in paragraphs below.

The controller **28** may include the microprocessor **84** and/or other analog and/or digital circuitry for processing one or more routines. Also, the controller **28** may include the memory **86** for storing one or more routines, including a trailer wheel base estimation routine **120**, a trailer sideswipe avoidance routine **98**, and a desired steering wheel angle routine **130**. It should be appreciated that the controller **28** may be a stand-alone dedicated controller or may be a shared controller integrated with other control functions, such as integrated with the sensor system **16**, the power assist steering system **62**, and other conceivable onboard or off-board vehicle control systems.

With reference to FIGS. **5** and **6**, we now turn to a discussion of vehicle **14** and trailer **12** information and parameters used to determine a kinematic relationship between the vehicle **14** and the trailer **12** for use in the trailer sideswipe avoidance routine **98**. This kinematic relationship may be useful in determining what the travel path of the trailer **12** may be and whether the travel path coincides with objects **15** within the operating environment **24** of the vehicle **14**, such that a sideswipe event would result. In describing the kinematic relationship, certain assumptions may be made with regard to parameters associated with the vehicle **14** and/or the trailer **12**. Examples of such assumptions include, but are not limited to, the wheels **64** of the vehicle **14** and the trailer **12** having negligible (e.g., no) slip, tires of the vehicle **14** having negligible (e.g., no) lateral compliance, tires of the vehicle **14** and the trailer **12** having negligible (e.g., no) deformation, actuator dynamics of the vehicle **14** being negligible, and the vehicle **14** and the trailer **12** exhibiting negligible (e.g., no) roll or pitch motions, among other conceivable factors with the potential to have an effect on controlling the trailer **12** with the vehicle **14**.

As shown in FIG. **5**, for a system defined by the combination of the vehicle **14** and the towed trailer **12**, the kinematic relationship is based on various parameters associated with the vehicle **14** and the trailer **12**. These parameters may include:

δ: steering angle at steered front wheels **64** of the vehicle **14**;

α: yaw angle of the vehicle **14**;

β: yaw angle of the trailer **12**;

γ: hitch angle ($\gamma=\beta-\alpha$);

W: wheel base of the vehicle **14**;

L: length between hitch point and rear axle of the vehicle **14**;

D: trailer wheel base, i.e. distance between hitch point and axle of the trailer **12** or effective axle for a multiple axle trailer **12** (axle length may be an equivalent);

r_t: dynamic turning radius of the trailer **12**;

V_w: width of the vehicle **14**;

T_w: width of the trailer **12**;

v_1: vehicle speed;

v_2: trailer speed;

ω_1: vehicle yaw rate; and

ω_2: trailer yaw rate.

It is contemplated that there may be various parameters utilized in determining the kinematic relationship between the vehicle **14** and the trailer **12** that are generally fixed and correspond to the dimensions of the vehicle **14** and trailer **12** combination. Specifically, the trailer wheel base D, the wheel base W of the vehicle **14**, and the length L between the hitch point and the rear axle of the vehicle **14** may be generally fixed and may be stored in memory **86**, whereas other parameters may be dynamic and obtained from the sensor system **16** on an ongoing basis. It is noted that the wheel base W of the vehicle **14** and the length L between the hitch point and the rear axle of the vehicle **14** relate only to the vehicle **14** itself, within which the controller **28** and, accordingly, memory **86** are installed. It follows, then, that these parameters may be stored in memory **86** during manufacture of vehicle **14**, or during installation of the relevant portions of the vehicle **14**, as they are known in relation to the specific make and model of the particular vehicle **14**.

In some embodiments, an assumption may be made by the trailer sideswipe avoidance system **10** that the length L between the hitch point and the rear axle of the vehicle **14** is equal to zero for purposes of operating the trailer sideswipe avoidance system **10** when a gooseneck trailer or other similar trailer **12** is connected with the hitch ball or a fifth wheel connector located over the rear axle of the vehicle **14**. Such an embodiment assumes that the pivoting connection with the trailer **12** is substantially vertically aligned with the rear axle of the vehicle **14**. Further, the controller **28** may be configured with modified algorithms to account for this assumption in operation of the trailer sideswipe avoidance system **10**. It is appreciated that the gooseneck trailer mentioned generally refers to the tongue configuration being elevated to attach with the vehicle **14** at an elevated location over the rear axle, such as within a bed of a truck, whereby embodiments of the gooseneck trailer may include flatbed cargo areas, enclosed cargo areas, campers, cattle trailers, horse trailers, lowboy trailers, and other conceivable trailers with such a tongue configuration.

Contrary to fixed vehicle parameters (e.g., L, W), the trailer wheel base D, while fixed with respect to a given trailer **12** that is coupled to the vehicle **14**, may vary as different trailers **12** are hitched to vehicle **14** for towing thereby. Further, the particular trailer **12** with which a given

vehicle **14** will be used may not be known during manufacture of vehicle **14**, and a user of such vehicle **14** may wish to use the vehicle **14** with various trailers **12** of different sizes and configurations. Accordingly, a routine or other method for the trailer sideswipe avoidance system **10** to obtain the particular trailer wheel base D may be needed and, in some embodiments, may be required for the trailer sideswipe avoidance system **10** to operate.

In some embodiments, vehicle **14** may include various features to facilitate the accurate measuring of the trailer wheel base D by a user. In particular, such features may provide a mechanism to allow flexibility for the user in measuring trailer wheel base D with a reduced risk of error and a streamlined process for inputting the measured value for the trailer wheel base D without manual numeric input using HMI **80** or the like. In a particular aspect, an encoder similar to an electronic tape measure device may be mounted on the rear of vehicle **14**. The encoder may include a string, wire, tape, or similar structure that can be extended outwardly from vehicle **14** by a user until it extends to the first axle of the trailer **12** installed with vehicle **14**. The module, would automatically read the distance by which the measuring structure is extended from the module, either by reading a series of visible, physical, or magnetic markings along the measuring structure, or using a potentiometer operably coupled with a reel on which the measuring structure is stored. The module can be electrically coupled with controller **28** or the like such that controller **28** can store the measured trailer wheel base D in memory **86** (which, in an example, can correspond to a maximum length of withdrawn measuring structure prior to release by the user and withdrawing thereof by the module). In one example, controller **28** can be restricted in storing such a measurement to when a "calibration mode" has been entered, such as by a user, when a new trailer **12** has been installed with the vehicle **14**.

In some embodiments, a short-range radar module may be included in the sensor system **16** of the vehicle **14**. Such short-range radar may be electrically coupled with and used by controller **28** to locate one or more "corner cubes" that can be strategically placed on trailer **12** in relation to (e.g. directly above) the front axle thereof. Corner cubes are generally known and are accepted as reliable reflectors of radar and can be used reliably for distance measurements. In an example, corner cubes with magnetic bases can be provided with vehicle **14** for mounting on the particular trailer **12** installed with vehicle **14** at a given time. Further, by using a triangulation method, two corner cubes placed on opposite sides of trailer **12** may also be used to determine the hitch angle γ.

In some embodiments, controller **28** may implement a trailer wheel base estimation routine **120** as-needed to determine the trailer wheel base D within a desired degree of accuracy. In particular, the trailer wheel base estimation routine **120** may utilize an estimate of hitch angle γ determined by the trailer sideswipe avoidance system **10** to derive an estimate for trailer wheel base D. A number of trailer wheel base estimates, taken at regular time intervals over one or more identified periods in which conditions allow for such estimates, can be averaged or filtered to produce a final weighted estimate of trailer wheel base D. Such routines may be generally known in the art.

By utilizing these parameters as well as the other parameters listed above for a variety of calculations, the kinematic relationship between the vehicle **14** and the trailer **12** can be deduced, and whether the towed trailer **12** may sideswipe the object **15** detected in the operating environment **24** of the vehicle **14** may be determined, as described below.

Initially, a position of the hitch ball **40** (x_b, y_b) may be determined based on the position of the vehicle **14** (x, y), the vehicle yaw angle α, and the length L between the hitch point and rear axle of the vehicle **14**. This hitch ball **40** location (x_b, y_b) is given by the following equations:

$$x_b = x - L\cos\alpha$$

$$y_b = y - L\sin\alpha$$

In various embodiments, the position of the vehicle **14** (x, y) may be represented by a point where a line running along a rear axle of the vehicle **14** intersects a longitudinal centerline of the vehicle **14**, as shown in FIGS. **5** and **6**.

The trailer yaw angle β may be determined by utilizing the above-mentioned vehicle yaw angle α and the determined hitch angle γ, via the following equation:

$$\beta = \gamma + \alpha$$

The trailer yaw rate ω_2 may be determined with the hitch angle γ, the trailer wheel base D, the vehicle speed v_1, and the vehicle yaw rate ω_1, via the following equation:

$$\omega_2 = -\frac{v_1}{D}\sin\gamma - \frac{L}{D}\cos\gamma\omega_1$$

The trailer speed v_2 may be determined with the length L between the hitch point and the rear axle of the vehicle **14**, the vehicle yaw rate ω_1, the vehicle speed v_1, and the hitch angle γ, via the following equation:

$$v_2 = v_1\cos\gamma - L\sin\gamma\omega_1$$

Next, the dynamic trailer turning radius r_t may be determined by dividing the determined trailer speed v_2 by the trailer yaw rate ω_2:

$$r_t = \frac{v_2}{\omega_2}$$

For the purposes of operating the trailer sideswipe avoidance system **10**, the dynamic trailer turning radius r_t may be limited to maximum value R_{max} such that:

$$-R_{max} \le r_t \le R_{max}$$

The position of the trailer (x_t, y_t) may be determined by using the hitch ball **40** location calculated above (x_b, y_b), the trailer wheel base D, and the trailer yaw angle β, via the following equations:

$$x_t = x_b - D\cos\beta$$

$$y_t = y_b - D\sin\beta$$

Next, the coordinates of the trailer turn center O (x_c, y_c) may be determined with the determined position of the trailer (x_t, y_t), the dynamic trailer turning radius r_t, and the trailer yaw angle β, via the following equations:

$$x_c = x_t - r_t\sin\beta$$

$$y_c = y_t + r_t\cos\beta$$

Having calculated the trailer turning center O, the distance r_{obj} of an object **15** from the trailer turning center O may be determined with the steering angle δ at the steered front wheels **64** of the vehicle **14**, the coordinates of the trailer

turn center O (x_c, y_c), and the position of the object **15** (x_{obj}, y_{obj}), via the following equation:)

$$r_{obj}=\text{sign}(\delta)\sqrt{(x_c-x_{obj})^2+(y_c-y_{obj})^2}$$

As discussed above, the position of the object **15** (x_{obj}, y_{obj}) may be determined by the virtual sensor system **18** or through the use of a variety of other sensors and devices contemplated within the sensor system **16** of the present disclosure. Further, as discussed above, the steering angle δ may be based on data collected from the steering angle sensor **67**.

Next, the trailer sideswipe avoidance system **10** may determine whether the detected object **15** is in the travel path of the trailer **12** relative to the trailer turning center O. Referring now to FIG. **6**, the sideswipe avoidance system **10** may utilize an inner trailer boundary line **90** extending between point A and point B, where point A is an intersection between an inner side **13** of the trailer **12** and a line extending outward along the axis of a trailer axle, and point B is a point displaced from point A a distance equal to the length of trailer wheel base D in the trailer forward direction substantially parallel to a longitudinal centerline of the trailer **12**. The inner side **13** of the trailer **12** may be the side of the trailer **12** that is generally facing the trailer turning center O. Accordingly, the inner side **13** of the trailer **12** may correspond with the turning direction of the vehicle **14**. For example, the inner side **13** of the trailer **12** may be the left side of the trailer **12** when the vehicle **14** is turning left, while the inner side **13** of the trailer **12** may be the right side of the trailer **12** when the vehicle **14** is turning right, as illustrated in FIG. **6**. The location of point A (x_A, y_A) may be determined with the position of the trailer (x_t, y_t), the trailer yaw rate ω_2, the trailer width Tw, and the trailer yaw angle β, via the following equations:

$$x_A = x_t - \text{sign}(\omega_2)\frac{Tw}{2}\sin\beta$$

$$y_A = y_t + \text{sign}(\omega_2)\frac{Tw}{2}\cos\beta$$

The location of point B (X_B, y_B) may be determined with the position of the trailer (x_t, y_t), the trailer yaw rate ω_2, the trailer width Tw, the trailer yaw angle β, and the trailer wheel base D, via the following equations:

$$x_B = x_t + D\cos\beta - \text{sign}(\omega_2)\frac{Tw}{2}\sin\beta$$

$$y_B = y_t + D\cos\beta + \text{sign}(\omega_2)\frac{Tw}{2}\cos\beta$$

Referring further to FIG. **6**, having determined the coordinates of point A and point B, the trailer sideswipe avoidance system **10** next determines whether the inner trailer boundary line **90** extending between point A and point B intersects a virtual circle **92** having a radius of r_{obj} (the distance of the detected object **15** from the trailer turning center O) and a center (x_c, y_c) (the coordinates of the trailer turn center O). If the inner trailer boundary line **90** is found to intersect the virtual circle **92**, the trailer sideswipe avoidance system **10** determines that the object **15** is in the travel path of the trailer **12**, such that a sideswipe event may occur.

When the trailer sideswipe avoidance system **10** determines that the inner trailer boundary line **90** intersects the virtual circle **92**, such that the object **15** is in the travel path of the trailer **12**, the trailer sideswipe avoidance system **10** may further determine the intersection point M (x_M, y_M) of the inner trailer boundary line **90** and the virtual circle **92**. The intersection point M (x_M, y_M) may be determined with the following:

Defining

$$d_x = x_B - x_A$$

$$d_y = y_B - y_A$$

$$d_r = \sqrt{d_x^2 + d_y^2}$$

$$Q = \begin{vmatrix} xA & xB \\ yA & yB \end{vmatrix} = x_A y_B - x_B y_A$$

gives the intersection point M (x_M, y_M)

$$x_M = \frac{Qd_y \pm \text{sgn}^*(d_y)d_x\sqrt{r_{obj}^2 d_r^2 - Q^2}}{d_r^2}$$

$$y_M = \frac{-Qd_x \pm |d_y|\sqrt{r_{obj}^2 d_r^2 - Q^2}}{d_r^2}$$

Where the function sgn*(x) is defined as

$$\text{sgn}^*(x) \equiv \begin{cases} -1 & \text{for } x < 0 \\ 1 & \text{otherwise} \end{cases}.$$

With the calculated intersection point M (x_M, y_M) the angle θ between lines running from the trailer turn center O (x_c, y_c) to the intersection point M (x_M, y_M) and the trailer turn center O (x_c, y_c) to the position of the object **15** (x_{obj}, y_{obj}) may be determined using the law of cosines. The angle θ may then be used in conjunction with the dynamic trailer turning radius r_t and the trailer speed v_2 to determine the time until sideswiping t_{ss} of the object **15** with the trailer **12**, via the following equation:

$$t_{ss} = \frac{\theta r_t}{v_2}$$

Referring back to FIG. **2**, in various embodiments, the controller **28** of the trailer sideswipe avoidance system **10** may prompt one or more vehicle systems to execute a sideswipe avoidance measure when the object **15** is determined to be in the travel path of the trailer **12**. For example, in some embodiments, the controller **28** may prompt the vehicle alert system **76** to execute a warning signal to inform the driver of the vehicle **14** or others that the object **15** is in the travel path of the trailer **12**. It is contemplated that the warning signal may be at least one of a variety of types of warning signals that may include, but is not limited to, visual warnings, auditory warnings, tactile warnings, and/or a combination thereof.

In some embodiments, the controller **28** may prompt the power assist steering system **62** to reduce the manual steering torque assist when the object **15** is determined to be in the travel path of the trailer **12**. For example, in some embodiments, when the object **15** is determined to be in the travel path of the vehicle **14** as the vehicle **14** is turning to

the right, the power assist steering system **62** may reduce the manual steering torque assist provided for steering actions by the driver that would further turn the vehicle **14** to the right. As such, the power assist steering system **62** may be configured to inhibit manual steering by a driver that would result in a sideswipe event happening more quickly or more severely. It is contemplated that, in some embodiments, the controller **28** may prompt the power assist steering system **62** to reduce the manual steering torque assist supplied when the object **15** is not in the travel path of the trailer **12**. For example, the controller **28** may prompt the power assist steering system **62** to reduce the manual steering torque assist supplied when over-steering the vehicle **14** would result in the travel path of the vehicle intersecting with the object **15**. In this way, a sideswipe avoidance measure may be employed preemptively to ensure that the trailer **12** does not collide with the object **15**. It is contemplated that, in some embodiments, the manual steering torque assist of the power assist steering system **62** may be utilized affirmatively to prevent the driver from turning in a given direction.

In some embodiments, the controller **28** may prompt the vehicle brake control system **72** and/or the powertrain control system **74** to adjust the speed of the vehicle **14** when the object **15** detected in the operating environment **24** of the vehicle **14** is determined to be in the travel path of the trailer **12**. For example, in some embodiments, the controller **28** may prompt the powertrain control system **74** and the vehicle brake control system **72** to work in unison to reduce the speed of the vehicle **14**. It is contemplated that, in some embodiments, the controller **28** may prompt execution of a sideswipe avoidance measure that stops the vehicle **14**.

In some embodiments, the controller **28** may prompt various vehicle systems (e.g., the power assist steering system **62**, the vehicle brake control system **72**, the powertrain control system **74**, etc.) to control movement of the vehicle **14** such that the predicted sideswipe event is avoided or mitigated. For example, in some embodiments, the controller **28** may prompt the vehicle systems to reduce the steering angle δ of the vehicle **14** such that dynamic turning radius of the vehicle **14** and/or the dynamic trailer turning radius r_t increases. The controller **28** may direct the vehicle systems to reduce the steering angle δ such that the travel path of the trailer **12** no longer overlaps with the position of the object **15**. For example, in some embodiments, the controller **28** may direct the vehicle systems to reduce the steering angle δ of the vehicle **14** such that the inner trailer boundary line **90** no longer intersects the virtual circle **92**.

Referring now to FIG. **7**, in some embodiments, the trailer sideswipe avoidance system **10** may use the following logic to adjust the steering angle δ of the vehicle **14** to avoid a sideswipe event as desired. First, a desired hitch angle γ_d may be determined with the length L between the hitch point and the rear axle of the vehicle **14**, the trailer wheel base D, and the distance r_{obj} of the object **15** from the trailer turning center O. Note that:

$$r_{obj} = \frac{L + D\cos\gamma_d}{\sin\gamma_d}$$

Accordingly, by rearranging the above equation and applying $\sin^2\gamma_d+\cos^2\gamma_d=1$ $r_{obj}\sin\gamma_d=L+D\cos\gamma_d$

As such,

$$\gamma_d = \sin^{-1}\frac{Lr_{obj} + D\sqrt{D^2 - L^2 + r_{obj}^2}}{D^2 + r_{obj}^2}$$

Next, a feedforward steering angle δ_{ff} may be determined with the length L between the hitch point and the rear axle of the vehicle **14**, wheel base W of the vehicle **14**, the trailer wheel base D, and the desired hitch angle γ_d, via the following equation:

$$\tan\delta_{ff} = -\frac{W\sin\gamma_d}{D + L\cos\gamma_d}$$

The feedforward steering angle δ_{ff} may be utilized by the controller **28** along with values from various calculations discussed above in the desired steering wheel angle routine **130** to determine a desired steering wheel angle SW_d necessary to avoid sideswiping the object **15** with the trailer **12**, as illustrated in FIG. **7**. The vehicle **14** (via the sensor system **16**) detects the object **15**, and the distance r_{obj} from the object **15** to the trailer turning center O is determined by the controller **28** in communication with the sensor system **16**. The distance r_{obj} from the object **15** to the trailer turning center O is then used to determine the desired hitch angle γ_d, which is, in turn, used to determine the feedforward steering angle δ_{ff}, as discussed above. The feedforward steering angle δ_{ff} may then be used to determine the desired steering wheel angle SW_d, which may prompt the various vehicle systems, such as the power assist steering system **62**, to control movement of the vehicle to avoid a sideswipe event with the object **15**. However, a variety of factors may contribute to error in the calculation of the feedforward steering angle δ_{ff}, which, without correction, may impede consistent avoidance of sideswipe events. Accordingly, as the feedforward steering angle δ_{ff} is determined, a feedback steering angle δ_{fb} is also determined and added to the feedforward steering angle δ_{ff} value, and the resulting value ($\delta_{ff}+\delta_{fb}$) is used by the controller **28** to calculate the desired steering wheel angle SW_d.

Referring further to FIG. **7**, in determining the feedback steering angle δ_{fb}, the trailer sideswipe avoidance system **10** of the vehicle **14** estimates a hitch angle γ and a trailer wheel base D, via the use of various vehicle systems and components, such as the sensor system **16** and data stored in memory **86** in the controller **28**. The hitch angle estimation and the trailer wheel base estimation are then processed by the controller **28** to determine the dynamic trailer turning radius r_t. The controller **28** then takes the absolute value of the dynamic trailer turning radius r_t and subtracts one half of the width Tw of the trailer **12** from the absolute value of the dynamic trailer turning radius r_t to obtain an inner radius r_{in} value, generally equal to the distance from the trailer turning center O to the inner side **13** of the trailer **12** proximate point A of the inner trailer boundary line **90**. The inner radius r_{in} is then subtracted from the calculated distance r_{obj} from the object **15** to the trailer turning center O. The resulting value (r_{obj}-r_{in}) is then input to a proportional integral derivative (PID) controller that is configured to calculate the feedback steering angle δ_{fb}, which, when added to the feedforward steering angle δ_{ff} may generally and/or substantially eliminate error that may occur in the trailer sideswipe avoidance system **10**. The summed feedforward steering angle δ_{ff} and feedback steering angle δ_{fb} are then used by the controller **28** to prompt the power assist steering system **62** and/or other

vehicle systems to adjust the steering wheel angle to the desired steering wheel angle SW_d and/or otherwise influence movement of the vehicle **14**, such that the inner trailer boundary line **90** no longer intersects the virtual circle **92**, and a sideswipe event may be avoided. It is contemplated that, in some embodiments, in which the vehicle **14** is equipped with a steering wheel **68** that is mechanically decoupled from the steering system (steer by wire), the trailer sideswipe avoidance system **10** may adjust the steering angle δ of the vehicle **14** without adjusting the steering wheel angle.

Referring now to FIG. **2**, the controller **28** of the trailer sideswipe avoidance system **10** may prompt one or more vehicle systems to execute a sideswipe avoidance measure based on time until sideswiping t_{ss}. In some embodiments, a sideswipe avoidance measure may be executed when the time until sideswiping t_{ss} is less than a threshold time value. In various embodiments, the threshold time value may be a predetermined value. In some examples, the threshold time value may be a fixed predetermined value that is stored in memory **86**. Further, in some examples, the threshold time value may vary based on certain conditions in accordance with predetermined logic of the controller **28**. For example, in some embodiments, the threshold time value may depend on at least one of a variety of conditions that may include, but is not limited to, vehicle speed v_1, trailer **12** dimensions, steering angle δ, size of detected object **15**, object **15** type classifications, and/or a combination thereof.

Referring further to FIG. **2**, in some embodiments, the controller **28** of the trailer sideswipe avoidance system **10** may prompt one or more vehicle systems to execute a first sideswipe avoidance measure when the time until sideswiping t_{ss} is less than a first predetermined threshold time value and prompt one or more vehicle systems to execute a second sideswipe avoidance measure when the time until sideswiping t_{ss} is less than a second predetermined threshold time value, wherein the first predetermined threshold time value is greater than the second predetermined threshold time value. For example, in some embodiments, the controller **28** of the trailer sideswipe avoidance system **10** may prompt the vehicle alert system **76** to execute a warning signal when the time until sideswiping t_{ss} is less than 3 seconds and prompt the power assist steering system **62** to adjust the steering wheel angle when the time until sideswiping t_{ss} is less than 1.5 seconds. It is contemplated that, in some embodiments, the controller **28** of the trailer sideswipe avoidance system **10** may prompt one or more vehicle systems to execute a plurality of sideswipe avoidance measures based on the time until sideswiping t_{ss} coinciding with a plurality of threshold time values.

Referring now to FIG. **8**, an embodiment of the trailer sideswipe avoidance routine **98** for use in the trailer sideswipe avoidance system **10** is illustrated. In the illustrated embodiment, the trailer sideswipe avoidance routine **98** begins in step **100** by receiving signals from the sensor system **16** of the vehicle **14**. These signals may pertain to parameters and conditions relating the vehicle **14**, the trailer **12**, and/or the object **15**.

At step **102** the received signals may be utilized to estimate various vehicle **14** and/or trailer **12** parameters. For example, in various examples, the received signals may be used to estimate the hitch angle γ, the trailer wheel base D, and the trailer width Tw. It is contemplated that in some examples, other vehicle **14** and/or trailer **12** parameters may be estimated additionally.

At step **104**, the trailer sideswipe avoidance system **10** may determine the dynamic trailer turning radius r_t and the trailer turn center O. Next, at step **106**, the trailer sideswipe avoidance system **10** may determine the distance r_{obj} from the trailer turn center O to the object **15**. At step **108**, the trailer sideswipe avoidance system **10** may determine the position of the inner trailer boundary line **90** extending between point A and point B. In various examples, the position of the inner trailer boundary line **90** is obtained by first determining point A and point B.

Next, at step **110**, the trailer sideswipe avoidance system **10** determines whether the inner trailer boundary line **90** intersects the virtual circle **92** having radius of r_{obj} (the distance of the detected object **15** from the trailer turning center O) and center (x_c, y_c) (the coordinates of the trailer turn center O). If the inner trailer boundary line **90** does not intersect the virtual circle **92** then the trailer sideswipe avoidance routine **98** may conclude or in some embodiments, return to the beginning and start again. If the inner trailer boundary line **90** does intersect the virtual circle **92**, then the trailer sideswipe avoidance routine **98** may continue to step **112**. However, as is illustrated by the dashed arrow in FIG. **8**, in some examples, the trailer sideswipe avoidance routine **98** may proceed directly to step **116** upon a determination that the inner trailer boundary line **90** does intersect the virtual circle **92**, wherein the controller **28** of the trailer sideswipe avoidance system **10** is configured to prompt one or more vehicle systems to execute the sideswipe avoidance measure. In various embodiments, the trailer sideswipe avoidance routine **98** proceeding directly to step **116** may be in addition to the trailer sideswipe avoidance routine **98** proceeding to step **112** or as an alternative.

At step **112**, the controller **28** of the trailer sideswipe avoidance system **10** is configured to determine the time until sideswiping t_{ss} of the object **15** with the trailer **12**. Next, at step **114**, the trailer sideswipe avoidance system **10** determines whether the time until sideswiping t_{ss} is less than the threshold time value. If the time until sideswiping t_{ss} is not less than a threshold time value, the trailer sideswipe avoidance routine **98** may return to the beginning of the routine and start again. If the time until sideswiping t_{ss} is less than a threshold time value, the trailer sideswipe avoidance routine **98** may proceed to step **116**, wherein the controller **28** of the trailer sideswipe avoidance system **10** is configured to prompt one or more vehicle systems to execute the sideswipe avoidance measure.

Referring now to FIG. **9**, a method **150** of operating the trailer sideswipe avoidance system **10** is illustrated. The method **150** includes the step **152** of operating the vehicle **14**. The step **152** of operating the vehicle may include driving the vehicle **14**. Further, it may include driving the vehicle **14** in the generally forward direction while towing the trailer **12**. The step **152** of operating the vehicle **14** may further include turning the vehicle **14** while towing the trailer **12** in the forward direction.

In various embodiments, the method **150** of operating the trailer sideswipe avoidance system **10** may further include the step **154** of determining vehicle **14** and/or trailer **12** conditions. The step **154** may encompass determining a variety of vehicle **14** and/or trailer **12** conditions and/or parameters. For example, in some embodiments, the step **154** may include estimating and/or determining at least one of a host of vehicle and/or trailer parameters and/or conditions that may include, but is not limited to, the hitch angle γ, the speed of the trailer v_2, the trailer wheel base D, and the trailer width Tw, the dynamic trailer turning radius r_t, the trailer turning center O, and/or the position of the inner trailer boundary line **90**.

In various embodiments, the method **150** of operating the trailer sideswipe avoidance system **10** may further include the step **156** of detecting objects **15** in the operating environment **24** of the vehicle **14**. In some embodiments, the sensor system **16** may be configured to detect the object **15**. In some embodiments, the virtual sensor system **18** may detect the object **15**. The position of the object **15** detected may be determined by the controller **28** in communication with the sensor system **16**.

The method **150** of operating the trailer sideswipe avoidance system **10** may further include the step **158** of determining a relationship between the object **15**, the vehicle **14**, and/or the trailer **12**. For example, in some embodiments, the step **158** may include determining the distance r_{obj} from the object **15** to the trailer turn center O. Further in some embodiments, the step **158** may include determining whether the inner trailer boundary line **90** intersects the virtual circle **92**. In various embodiments, the step **158** may include determining the time until sideswiping t_{ss} of the object **15** with the trailer **12**. As discussed above, in various embodiments, the time until sideswiping t_{ss} may be based on the speed of the trailer v_2, the dynamic trailer turning radius r_t, and the angle θ between the line extending from the trailer turn center O to the object **15** and the line extending from the trailer turn center O to the intersection point M of the inner trailer boundary line **90** and the virtual circle **92**. This angle θ is described above as being defined between lines running from the trailer turn center O (x_c, y_c) to the intersection point M (x_M, y_M) and the trailer turn center O (x_c, y_c) to the position of the object **15** (x_{obj}, y_{obj}). In some embodiments, the step **158** may include the controller **28** of the trailer sideswipe avoidance system **10** comparing the time until sideswiping t_{ss} to the threshold time value and/or a plurality of threshold time values. As discussed above, the one or more threshold time values may be predetermined.

The method **150** of operating the trailer sideswipe avoidance system **10** may further include the step **160** of executing the sideswipe avoidance measure. As discussed above, the controller **28** may prompt one or more vehicle systems to execute the sideswipe avoidance measure. The step **160** of executing the sideswipe avoidance measure may entail executing at least one of a host of types of sideswipe avoidance measures that may include, but is not limited to, executing a warning signal via the vehicle alert system **76**, reducing the steering angle δ of the vehicle **14** such that the inner trailer boundary line **90** no longer intersects the virtual circle **92**, reducing manual steering torque assist supplied by a power assist steering system, reducing the speed of the vehicle **14**, and/or a combination thereof. It should be appreciated that various other sideswipe avoidance measures disclosed herein may be performed via step **160** of the method **150** of operating the trailer sideswipe avoidance system **10**. In various embodiments, the step **160** of executing the sideswipe avoidance measure may be entered into based on a determination that the object **15** is in the travel path of the trailer **12**. In some embodiments, the step **160** may be entered into based on a determination that the inner trailer boundary line **90** is intersecting the virtual circle **92**. In some embodiments, the step **160** may be entered into based on a determination the time until sideswiping t_{ss} is less than the predetermined threshold time value.

The present disclosure may provide a variety of advantages. For example, operation of the trailer sideswipe avoidance system **10** may enable the controller **28** to prompt the vehicle alert system **76** to execute a warning signal that may warn the driver of the vehicle **14** or other person that the object **15** detected by the sensor system **16** is in the travel path of the trailer **12** being towed by the vehicle **14**, which may aid the driver in reacting to the situation. Further, in certain situations, operation of the trailer sideswipe avoidance system **10** may enable the controller **28** to prompt various other vehicle systems, such as the power assist steering system **62**, to actively adjust the steering angle δ of the vehicle **14** in response to a determination that the object **15** is in the travel path of trailer **12** and/or that the time until sideswiping t_{ss} is less than a predetermined threshold time value, which may allow for avoidance of a sideswipe event.

It is to be understood that variations and modifications can be made on the aforementioned structure without departing from the concepts of the present invention, and further it is to be understood that such concepts are intended to be covered by the following claims unless these claims by their language expressly state otherwise.

What is claimed is:

1. A trailer sideswipe avoidance system for a vehicle towing a trailer in a forward direction, comprising:

a sensor system configured to detect objects in an operating environment of the vehicle; and

a controller configured to process information received from the sensor system to determine whether an object detected in the operating environment of the vehicle is in a travel path of the forwardly towed trailer as the vehicle turns by determining whether an inner trailer boundary line intersects a virtual circle having a center point at a trailer turn center and a radius equal to the distance from the trailer turn center to the object, wherein the controller is further configured to prompt one or more vehicle systems to execute a sideswipe avoidance measure based on a determination that the object is in the travel path of the forwardly towed trailer.

2. The trailer sideswipe avoidance system of claim **1**, wherein the sideswipe avoidance measure comprises reducing manual steering torque assist supplied by a power assist steering system.

3. The trailer sideswipe avoidance system of claim **1**, wherein the sideswipe avoidance measure comprises executing a warning signal via a vehicle alert system.

4. The trailer sideswipe avoidance system of claim **1**, wherein the sideswipe avoidance measure comprises reducing the speed of the vehicle.

5. The trailer sideswipe avoidance system of claim **1**, wherein the sideswipe avoidance measure comprises reducing a steering angle of the vehicle such that the dynamic turning radius of the vehicle increases.

6. The trailer sideswipe avoidance system of claim **1**, wherein the controller is further configured to determine a time until sideswiping of the object with the towed trailer.

7. The trailer sideswipe avoidance system of claim **6**, wherein the controller is further configured to prompt one or more vehicle systems to execute the sideswipe avoidance measure when the time until sideswiping is less than a predetermined threshold time value.

8. The trailer sideswipe avoidance system of claim **6**, wherein the controller is further configured to prompt one or more vehicle systems to execute a first sideswipe avoidance measure when the time until sideswiping is less than a first predetermined threshold time value and prompt one or more vehicle systems to execute a second sideswipe avoidance measure when the time until sideswiping is less than a second predetermined threshold time value, wherein the first predetermined threshold time value is greater than the second predetermined threshold time value.

9. A trailer sideswipe avoidance system for a vehicle towing a trailer in a forward direction, comprising:

a sensor system configured to detect objects in an operating environment of the vehicle; and

a controller receiving inputs from the sensor system and configured to:

determine a travel path of the forwardly towed trailer as the vehicle turns;

determine whether an object detected in the operating environment of the vehicle is in the travel path of the forwardly towed trailer by determining whether an inner trailer boundary line intersects a virtual circle having a center point at a trailer turn center and a radius equal to the distance from the trailer turn center to the object;

determine a time until sideswiping of the object with the forwardly towed trailer;

compare the time until sideswiping with a threshold time value; and

prompt one or more vehicle systems to execute a sideswipe avoidance measure when the time until sideswiping is less than the threshold time value.

10. The trailer sideswipe avoidance system of claim 9, wherein the sideswipe avoidance measure comprises reducing manual steering torque assist supplied by a power assist steering system.

11. The trailer sideswipe avoidance system of claim 9, wherein the sideswipe avoidance measure comprises executing a warning signal via a vehicle alert system.

12. The trailer sideswipe avoidance system of claim 9, wherein the sideswipe avoidance measure comprises reducing the speed of the vehicle.

13. The trailer sideswipe avoidance system of claim 9, wherein the sideswipe avoidance measure comprises reducing a steering angle of the vehicle such that the dynamic turning radius of the vehicle increases.

14. A method for operating a trailer sideswipe avoidance system, comprising the steps of:

turning a vehicle towing a trailer in a forward direction;

determining a dynamic trailer turning radius and a trailer turn center;

detecting an object with a sensor system of the vehicle;

determining a distance from the trailer turn center to the object;

determining whether an inner trailer boundary line intersects a virtual circle having a center point at the trailer turn center and a radius equal to the distance from the trailer turn center to the object; and

executing a sideswipe avoidance measure based on the inner trailer boundary line intersecting the virtual circle.

15. The method of claim 14, wherein the inner trailer boundary line extends between a first point and a second point, the first point is located proximate to an intersection between an inner side of the trailer and a line running along the axis of a trailer axle, and the second point is displaced from the first point a distance generally equal to the length of the trailer wheel base in the trailer forward direction substantially parallel to a longitudinal centerline of the trailer, wherein the inner side of the trailer corresponds with a turning direction of the vehicle and the inner trailer boundary line is distanced from the longitudinal centerline of the trailer by at least the distance of the inner side of the trailer from the longitudinal centerline of the trailer in a direction parallel to the axis of the trailer axle.

16. The method of claim 15, further comprising the step of:

determining a time until sideswiping based on a speed of the trailer, the dynamic trailer turning radius, and the angle between a line extending from the trailer turn center to the object and a line extending from the trailer turn center to an intersection point of the inner trailer boundary line and the virtual circle.

17. The method of claim 16, further comprising the steps of:

comparing the time until sideswiping with a predetermined threshold time value; and

executing the sideswipe avoidance measure when the time until sideswiping is less than the predetermined threshold time value.

18. The method of claim 14, wherein the step of executing a sideswipe avoidance measure comprises:

executing a warning signal via a vehicle alert system.

19. The method of claim 14, wherein the step of executing a sideswipe avoidance measure comprises:

reducing a steering angle of the vehicle such that the inner trailer boundary line no longer intersects the virtual circle.

20. The method of claim 14, wherein the step of executing a sideswipe avoidance measure comprises:

reducing manual steering torque assist supplied by a power assist steering system.

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